DOT/FAA/CT-93/6

FAA Technical Center
Atlantic City International Airport
N.J. 08405

Results of DATAS Investigation of ATCRBS Environment at the Los Angeles International Airport

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April 1993

Final Report

U.S. Department of Transportation
Federal Aviation Administration

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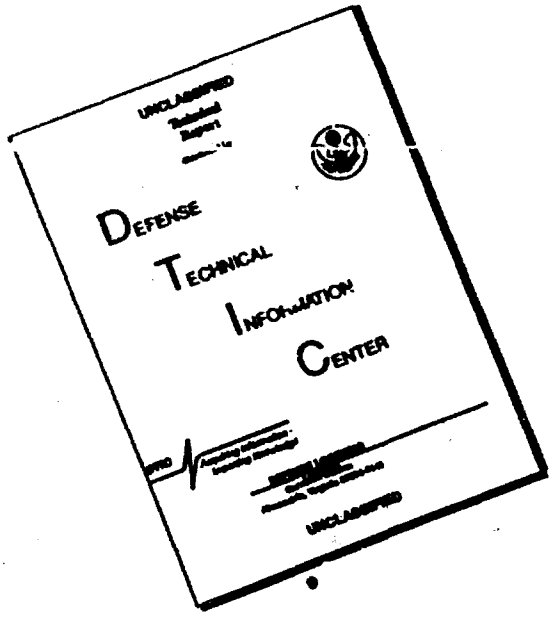

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-93/6		

4. Title and Subtitle	5. Report Date
RESULTS OF DATAS INVESTIGATION OF ATCRBS ENVIRONMENT AT THE LOS ANGELES INTERNATIONAL AIRPORT	April 1993
	6. Performing Organization Code: ACD-320
7. Author(s): Leo Wapelhorst, Thomas Pagano, and John Van Dongen	8. Performing Organization Report No.: DOT/FAA/CT-93/6
9. Performing Organization Name and Address: Department of Transportation, Research Directorate for Aviation Technology, Federal Aviation Administration Technical Center, Atlantic City International Airport, NJ 08405	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.: T1101F
12. Sponsoring Agency Name and Address: Department of Transportation, Federal Aviation Administration, 800 Independence Avenue, S.W., Washington, DC 20591	13. Type of Report and Period Covered: Final Report 12/14/92 - 01/15/93
	14. Sponsoring Agency Code: ARD-220T

15 Supplementary Notes

16. Abstract

This report documents the deployment of the Data Link Test and Analysis System (DATAS) as a Traffic Alert and Collision Avoidance System (TCAS) monitor at the Los Angeles International Airport (LAX). The purpose was to identify aircraft which were reporting illegal Mode S ID's. Data were also taken on the downlink portion of the environment in order to characterize the environment after the implementation of TCAS. The project was conducted by the Airborne Collision and Data Link Systems branch of the Federal Aviation Administration (FAA) Technical Center.

17. Key Words	18. Distribution Statement
DATAS TCAS ATCRBS Mode S ID's Los Angeles International Airport	This document is available to the public through the National Technical Information Service, Springfield, VA 22161

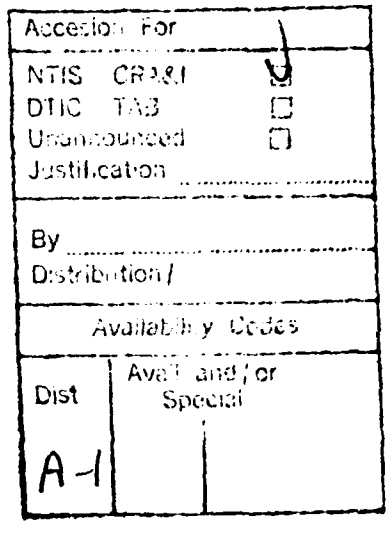
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	39	

ACKNOWLEDGEMENTS

The data presented in this report was acquired using the Data Link Test and Analysis System (DATAS). The DATAS was designed and modified to be a Traffic Alert and Collision Avoidance System (TCAS) monitor by the Mode Select (Mode S) ground Data Link development team.

Identification of the aircraft with illegal Mode S codes would not have been possible without the cooperation of Merle McClure of the Los Angeles Automation office at Los Angeles International Airport (LAX) and Jim Hampton of the Los Angeles Automation office at the Los Angeles Air Route Traffic Control Center (ARTCC). They were called upon to correlate the Air Traffic Control Radar Beacon System (ATCRBS) code issued by the aircraft and the time of coverage in order to get the flight information on the aircraft.

Acknowledgment is also given to Pablo Gaud of the Los Angeles Terminal Radar Approach Control Facility (TRACON), who allowed Federal Aviation Administration (FAA) Technical Center personnel to use his computer for data reduction during the data collection period.



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EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) Technical Center Data Link project personnel designed, developed, and deployed a system to record Traffic Alert and Collision Avoidance System (TCAS) activity. Through coordinated efforts with TCAS project personnel, the Data Link project design team modified the existing Data Link Test and Analysis System (DATAS) to perform as the TCAS monitor. This system was first deployed at Dallas/Fort Worth (DFW) Airport to collect data on Resolution Advisories (RA's). This system was later installed in a van and modified to function as an Illegal Mode Select (Mode S) ID search vehicle. It was then installed at John F. Kennedy (JFK) Airport in New York for the first deployment after this new capability. This report describes the installation at Los Angeles International Airport (LAX). The system was configured to store all interrogation/reply activity in order to establish a data base which could be used to investigate anomalies at a later time if desired. All transactions were "time tagged" so that data could be correlated with independent surveillance data from systems such as the Automated Radar Terminal System (ARTS) III, ARTS II, or Airport Surveillance Radar (ASR)-9.

The system was operational for the TCAS monitor data collection from December 14, 1992, to January 15, 1993. The system was operational 24 hours per day and data were retrieved via a cellular phone/modem link and analyzed at the FAA Technical Center. During that time, 17,700 Mode S flights involving 2,174 different aircraft were acquired. There were 16,600 domestic flights and 1,100 foreign flights. The domestic aircraft acquired reported 90 percent TCAS equippage, but the foreign aircraft only reported 20 percent.

There were a total of 117 flights with illegal Mode S ID's during the period. These illegal ID's fall into three basic categories:

1. Apparent wiring errors or misinterpretations of the specifications. The most predominant illegal addresses fell into this category. There were a total of 85 flights by five aircraft from two different airlines which provided this total.

2. All ones or all zeros. The next most common, and the most serious, were 27 flights with a Mode S address of all zeros. These were all provided by two foreign airlines. On January 5, there were two aircraft, with an all zero address, from the same airline which landed at LAX within a 10-minute interval, a potientally dangerous situation as either one (or both) may not be tracked by TCAS aircraft because of their address ambiguity.

3. Single bit errors. The single bit address errors may be occurring as a result of a "startup" problem. There is strong evidence that the same aircraft sometimes has the correct address and sometimes (for the entire duration of coverage) has an address which has a single bit error. One aircraft acquired at

LAX, which has been seen before with the single bit error at JFK, Philadelphia (PHL), and DFW has been tested on the ground without error.

Another problem previously encountered at JFK, continuous RA's reporting, also exists at LAX. Some commuter aircraft report that they have RA information available continuously. When polled for this information, the data fields which describe the advisory contain all zeroes. This appears to be a transponder (or transponder/TCAS interface) problem as the Reply Information (RI) field, which indicates the TCAS capability of the aircraft appears to work correctly (TCAS vertical resolution capability inhibits automatically at altitudes below 500 feet and the transponder reports this information correctly). The RA reporting function should "clear" after a period of 18 seconds.

The siting of the system provided incidental coverage while aircraft were on the ground. This enabled the investigation of system characteristics not previously available. As a result, future deployments will include ground coverage as part of siting criteria. It was found that some small percentage (12 out of 2,147) of aircraft are erroneously reporting their air/ground status. Six aircraft reported they were on the ground when they were actually as high as 29,000 feet. Six different aircraft reported that they were airborne when they were actually on the ground.

The next deployment of DATAS will be able to accurately describe the TCAS activity on the ground as the system will be configured to enhance ground coverage. The limited sample at LAX, however, gave some interesting results. It was seen that some aircraft leave their transponders or transponders and TCAS units on for more than 1 hour after landing. The majority, however, turned the units off within 1 to 2 minutes.

DATAS was also connected to the output of the Air Traffic Control Beacon Interrogator (ATCBI)-4 raw video to collect data on Air Traffic Control Radar Beacon System (ATCRBS) and Mode S fruit replies. Data were collected from January 26 to January 28. Fruit rates were much lower than expected. The highest Mode S fruit rate measured was 44 replies per second, certainly no problem to the existing ATCRBS system. New system capability enabled the analysis of Mode S reply data. It was determined that approximately 15 percent of the replies came from aircraft on the ground. Approximately 23 percent of the replies were "acquisition" replies, which indicate a large number of replies are dedicated to the initial TCAS acquisition process.

INTRODUCTION

Implementation of the Traffic Alert and Collision Avoidance System (TCAS) is now in progress as a result of legislation passed by Congress. This legislation also mandates a joint Federal Aviation Administration (FAA)/airline industry operational evaluation of the system. The TCAS Transition Program (TTP) requires data recording systems in order to provide data from several sources for analysis during the early stages of TCAS implementation.

The primary objectives of the TTP are to evaluate the operational performance of a large number of TCAS installations and assist in the integration of these units into the National Airspace System (NAS). Government, airline industry, and equipment manufacturers represented on the TTP will investigate and resolve all non-certification related operational problems associated with TCAS implementation.

The operation of the Mode Select (Mode S) System, and TCAS, which uses the Mode S protocol, relies on each aircraft having an unique address in order to selectively interrogate each aircraft. When not properly installed, the aircraft Mode S installations usually have an address of all zeroes or all ones. Neither of these are legal and can lead to ambiguities in the TCAS environment as transponders produced by different manufacturers do not react the same to these illegal addresses. The Data Link Test Analysis System (DATAS), developed at the FAA Technical Center, was modified to provide a TCAS monitor function in addition to its existing functions. DATAS, as a TCAS monitor, operated independently of the TCAS systems to collect TCAS data (such as Resolution Advisories (RA's) as well as illegal addresses) from the ground.

DATAS was also configured to collect data on the Air Traffic Control Radar Beacon System (ATCRBS)/Mode S downlink frequency (1090 megahertz (MHz)). Data were collected from January 26 to January 28. The "raw video" output of the Los Angeles Air Traffic Control Beacon Interrogator (ATCBI)-4 was used as the input to DATAS. New system capability enabled the analysis of Mode S reply data as well as ATCRBS and Mode S fruit counts per second.

SYSTEM CONFIGURATION

The user's guide for the TCAS monitor (report DOT/FAA/CT-TN90/62) also includes a more detailed description. The TCAS Monitor function is described in the report on testing at Dallas/Fort Worth (DFW) Airport (report DOT/FAA/CT-TN91/56). Other system modifications which evolved during previous testing are described in the reports covering testing at Chicago O'Hare (DOT/FAA/CT-92/22) and John F. Kennedy (JFK) International Airport (DOT/FAA/CT-92/26).

The DATAS (as used in the TCAS monitor application) basically operates like a Mode S sensor which is located near the terminal. The system used a horn antenna (beamwidth is approximately 35°) with power output reduced to provide coverage to approximately 30 miles. It monitors all Mode S equipped aircraft within this "azimuth wedge." Aircraft are acquired via standard Mode S All Call protocol. All interrogation/reply data are stored for all aircraft. This creates an extensive database which can provide information on many different system characteristics at a later time. The azimuth wedge for coverage by the DATAS was selected after coordination with Los Angeles International Airport (LAX) air traffic personnel. The basis for selection was the ability to collect data on both arrival and departures and insure coverage of foreign flights (suspected of being the source of most illegal Mode S ID's).

The DATAS equipment was installed in a van so that space for installation at existing sites was not required. The DATAS van was parked adjacent to the Airport Surveillance Radar (ASR)-9 at LAX. After the initial installation, the equipment was operated 24 hours a day as a completely unmanned facility for a period of approximately 1 month. Data were extracted via modem/cellular phone and analyzed at the FAA Technical Center. These data will be referred to as "TCAS Monitor Data" in this report. The coverage of aircraft while on the ground allowed the examination of system performance not previously available. As a result of this information, the coverage of aircraft while on the ground will also be used as a consideration when siting the DATAS van for coverage at a particular site. There was also an overnight run on January 25, 1993, when the antenna was turned to attempt better ground traffic coverage. It should be noted that aircraft in the air and those on the ground were grouped separately when analyzing the data.

The downlink data were collected at LAX over the 3-day period January 26-28, 1993. The system was setup at the ASR-9 radar site for connection to the ATCBI-4 receiver output. In this manner, the counts of ATCRBS and Mode S replies directly reflects the amount seen by the ground ATCRBS processing system. All Mode S reply data and counts of the ATCRBS and Mode S reply rates were stored for the data collection period. These data were then analyzed separate from the TCAS monitor data.

Throughout this report, the aircraft tail numbers and references to any particular airlines have been deleted. They are designated as Airline 1, Airline 2, etc., for purposes of following through the various graphs presented.

TCAS MONITOR DATA DISCUSSION - AIRBORNE AIRCRAFT

The DATAS installation at Los Angeles provided a means of recording TCAS equipage and capability reported by Mode S equipped aircraft. The data were collected from December 14, 1992, to January 15, 1993. The system was operational 24 hours a day with the exception of brief periods of down time during data retrieval and power outages. Data were collected for a total of

817.5 hours, during which a total of 369 megabytes of data were stored. The system monitored 17,700 flights involving 2,174 different aircraft overall. There were 16,600 domestic flights involving 1,912 different aircraft, and 1,100 foreign flights involving 262 different aircraft. This section compares foreign and domestic TCAS capability. Figure 1 shows the percentage of foreign, domestic, and illegal Mode S addresses recorded during the entire operation. The one percent illegal aircraft include those with all zero addresses as well as those with illegal country codes such as Airline 1, etc. This graph includes only airborne aircraft data. Figure 2 shows the origin of foreign air traffic recorded at Los Angeles. The black columns show the percentage of foreign flights and the white columns are the percentage of foreign aircraft from each country. For example, 14 percent of foreign aircraft and 10 percent of foreign flights were from Spain.

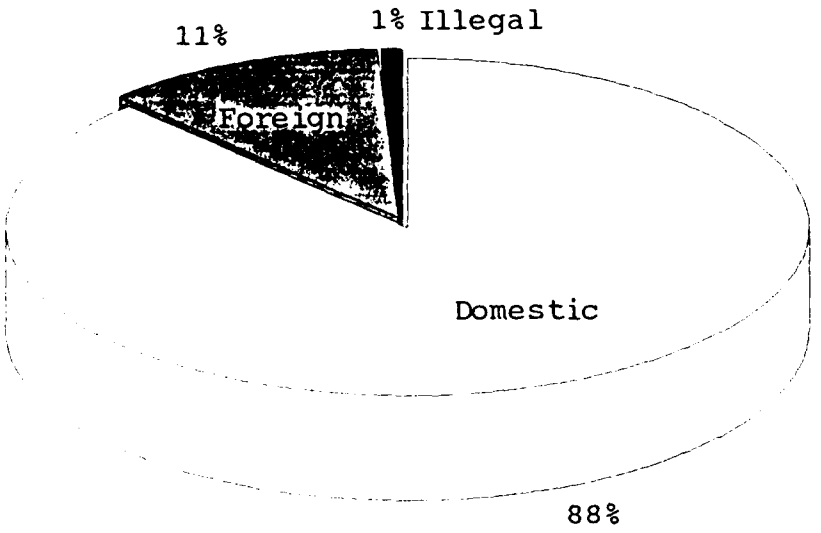

FIGURE 1. LAX AIRBORNE MODE S AIRCRAFT TYPES

Figure 3 shows the TCAS capability as reported by domestic aircraft. The three capability categories are: no TCAS, TCAS in Traffic Advisory (TA) only mode, and TCAS with vertical resolution capability (indicated by "TCAS" in chart). It cannot be determined whether aircraft reporting "no TCAS" are not equipped with TCAS or have TCAS turned off. The graph is divided into altitude ranges because TCAS capability automatically switches to TA only mode below 500 feet, and also to show any other variations in capability at different altitudes. The Mode S aircraft operating at or above 10,000 feet reported nearly 90 percent TCAS equipage. There is a percentage of aircraft operating in TA only mode at all altitudes. The graph shows the automatic switch to TA only mode at 500 feet with some variation due to barometric pressure and altitude

correction tolerance. There is a steady decrease in the percentage of active TCAS units at lower altitude ranges.

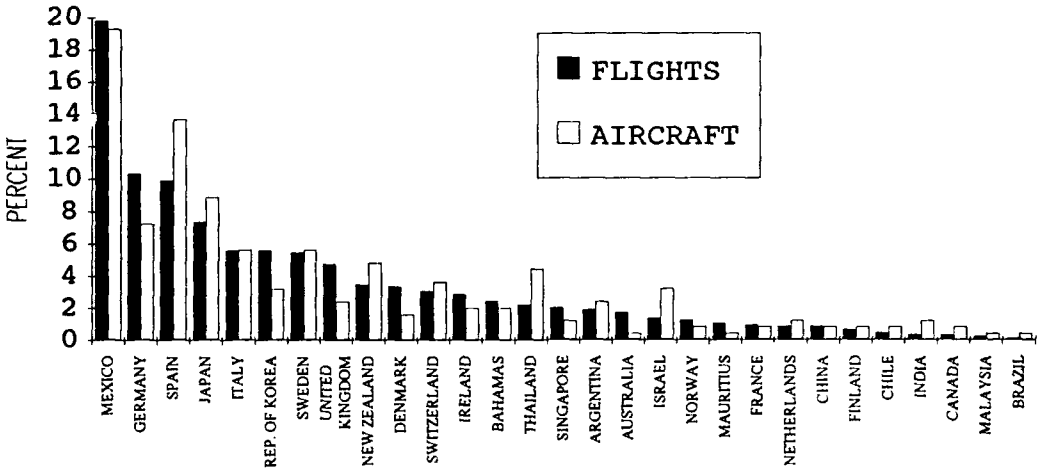

FIGURE 2. FOREIGN AIRCRAFT COUNTRIES

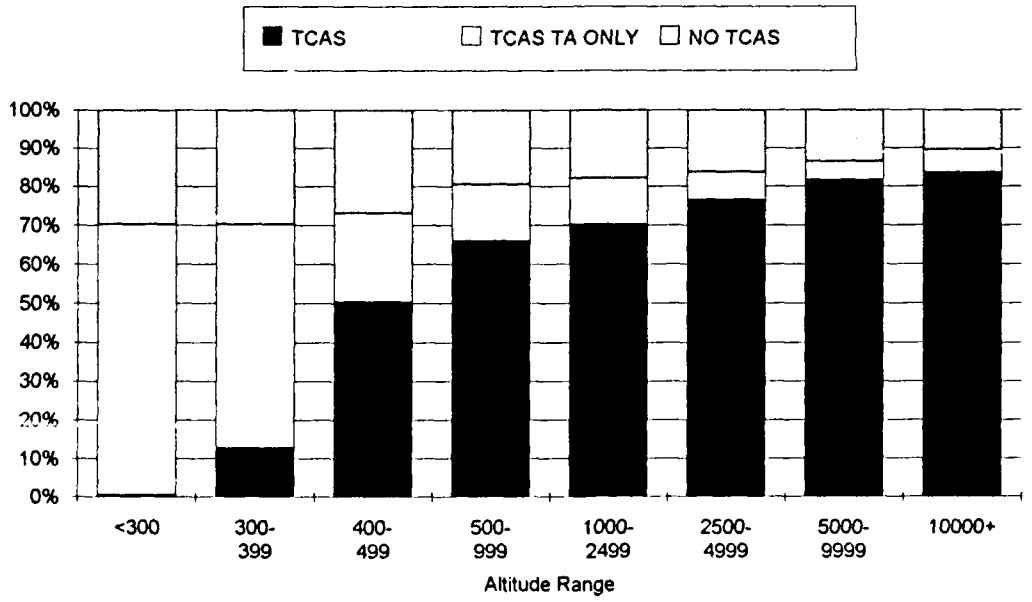

FIGURE 3. TCAS CAPABILITY REPORTED BY DOMESTIC MODE S EQUIPPED AIRCRAFT

Figure 4 is a similar graph for foreign aircraft. The data show that foreign Mode S aircraft are only about 20 percent equipped with TCAS. Figure 4 does

not include aircraft with illegal Mode S addresses. However, during data analysis, foreign and illegal data were combined and the graph was nearly identical to figure 3.

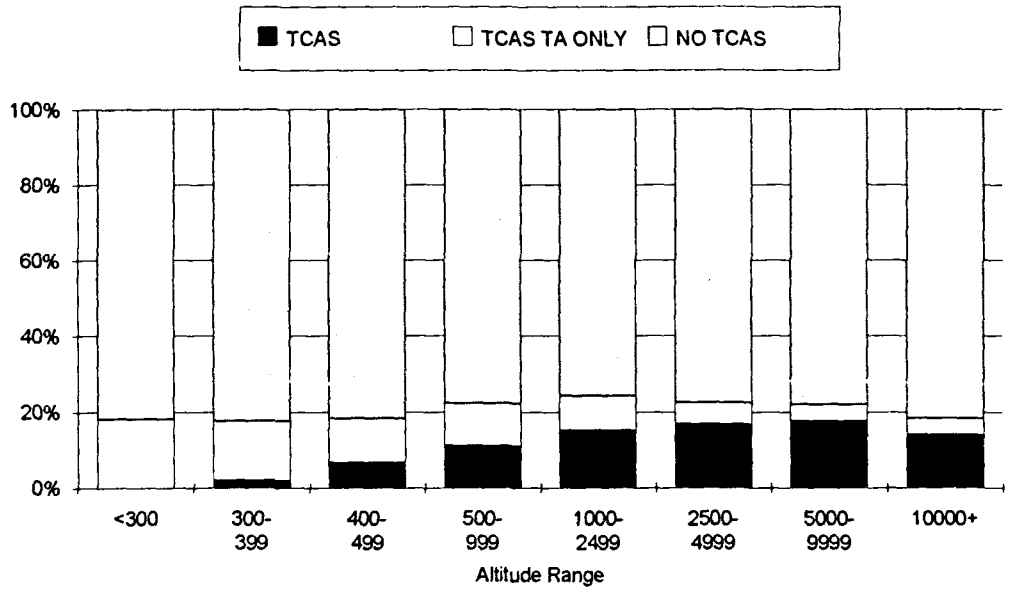

FIGURE 4. TCAS CAPABILITY REPORTED BY FOREIGN MODE S EQUIPPED AIRCRAFT

TCAS CAPABILITY ANALYSIS CRITERIA

The TCAS capability is provided in the Reply Information (RI) field in a special surveillance reply, Downlink Field value 0 (DF=0). A special surveillance interrogation is one of the two interrogations used during the normal 5-second surveillance scan as part of the TCAS monitor application, hence, TCAS capability is stored along with the rest of the data. The database was divided into each unique RI field value for each flight. The system attempts to store one record for each flight in "real-time," but this does not always work out due to aircraft flying in and out of coverage. To compensate, records for same aircraft with the same RI value and occurring within 15 minutes were combined. The same criteria was used to count the number of flights, except the RI field value was ignored because it changes as a function of altitude and TCAS status. The number of aircraft is simply the number of unique Mode S addresses. For all data analysis, there must be at least two valid Mode S replies from a target; single hit replies are eliminated from the database due to a high percentage of parity errors in such cases. Since DATAS does not provide real-time altimeter correction, the reported altitudes were adjusted later by subtracting the altitudes reported by on-ground targets nearest to the time of the airborne targets.

ON-GROUND TCAS CAPABILITY

DATAS was installed at Los Angeles primarily to monitor airborne arrival traffic. Because of the proximity of the van and antenna direction, a significant amount of ground traffic data was also collected. The ground coverage was not nearly as good as the air coverage because of the antenna tilt and direction. Most ground traffic interrogations were likely radiated by the antenna side lobes. There was also a lot of antenna shielding and reflections due to buildings and other aircraft. DATAS also uses a directional horn antenna and, therefore, covers only a geometric wedge shaped area, the center of which is intentionally aimed at airborne traffic. The resulting area of ground coverage is indeterminate. Based on a visual observation, it is unlikely that the center or most densely populated area of on-ground air traffic was covered by DATAS. *Therefore, the reader is cautioned to realize that the data presented on ground traffic are from an incidental sample and may or may not reflect the true population.* For future data collection efforts, the system will be set up in such a way as to best collect air and ground data.

The ground coverage provided records of 2,781 "flights" (14 percent of the total) and 1,016 aircraft (almost 1/2 of the total). There were 2,306 domestic and 475 foreign "flights," and there were 875 domestic aircraft and 141 foreign aircraft.

Domestic on-ground TCAS capability data are presented in figures 5 and 6. Rather than present the reported data as a function of altitude, for obvious reasons, the on-ground data are examined as a function of time. The interest is in how many and how long aircraft have transponders "on" while on the ground. The aircraft must have a Mode S transponder "on" to be recorded by DATAS. The gray columns in figure 5 show the percentage of aircraft that turned "off" their transponders within the specified time intervals (note that the time intervals are not uniform). The gray columns represent all on-ground Mode S activity recorded by DATAS, and therefore, the sum of all gray categories are equal to 100 percent. Nearly half of the transponders are operated for less than a half of a minute prior to take-off or after landing. Approximately 4 percent of active transponders were on for more than 30 minutes. The black and white columns represent the percentage of aircraft with TCAS "off" or "on", respectively (note the sum of black and white columns in each category will equal the gray columns). The apparent increase in transponder activity in the last three columns is only a result of increased time intervals.

In figure 6, the bar graph shows the percentage of replies that indicate if TCAS is on or off for various time intervals. Each duration category includes those equal and greater, in order to produce a curve. For example, of the domestic aircraft which had their transponder/TCAS on, 63 percent had TCAS in the TA

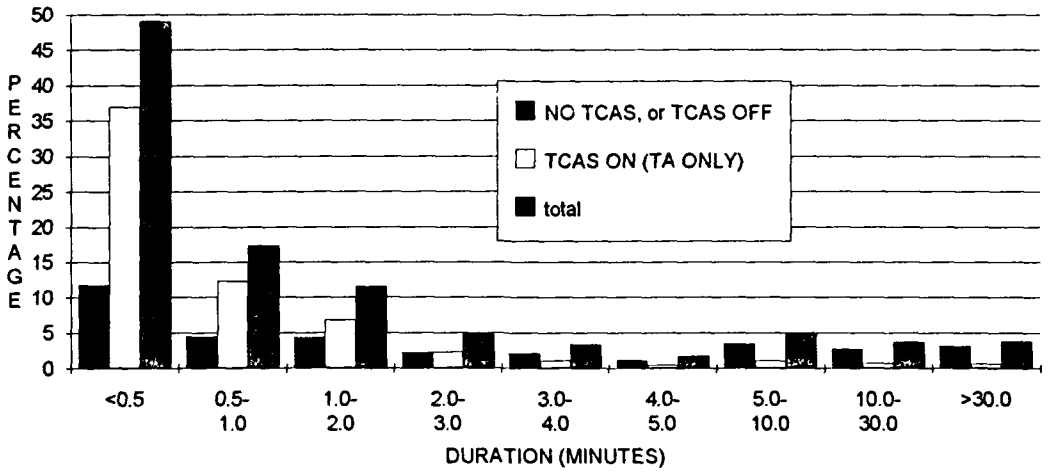

FIGURE 5. TCAS STATUS, ON-GROUND DOMESTIC AIRCRAFT

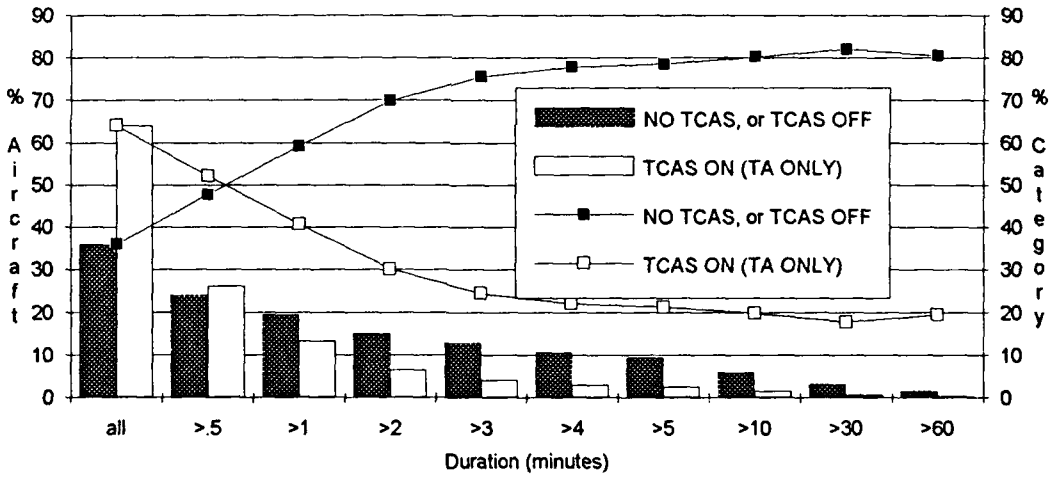

FIGURE 6. TCAS STATUS, ON-GROUND DOMESTIC AIRCRAFT PERCENTAGE CURVE

mode and the remaining 37 percent either had no TCAS or turned it off within 30 seconds after landing. Twenty-seven percent had the system on for longer than 0.5 minute, 12 percent had it on longer than 1 minute, etc. Most aircraft were tracked on the ground for less than 1/2 a minute, as indicated by the large number reported in the "all" category. The largest portion excluded when

progressing to the >0.5 minute category are those with TCAS. This may indicate that aircraft equipped with TCAS are more likely to turn off their transponders. As expected, there are fewer transponders on at longer time intervals. The line graph shows a smaller percentage of TCAS at longer time intervals. The right hand axes (Percent Category) describes the population which is remaining at each interval. For example, of the aircraft which have their systems on for more than an hour after landing, 80 percent either had no TCAS or had it off and the remaining 20 percent had the TCAS in the TA mode. *It is important to note that, again because of the limited ground coverage at LAX, the status duration presented here is not necessarily indicative of how long transponders and TCAS units are left on because it is unknown how many were turned off and how many aircraft taxied out of range of the system. .*

Foreign on-ground TCAS status data are presented in figures 7 and 8. The graphs are the same as those for domestic aircraft. Again, there are fewer transponders on at longer time intervals but the percentage with TCAS on actually increases. Figure 7 shows that, of the foreign aircraft, there is a higher percentage of aircraft with transponders and TCAS on at longer intervals. The fact that the bar graph in figure 8 is much more linear than the domestic graph indicates that foreign aircraft with TCAS are no more likely to turn off their transponders than those without TCAS. Also, the percentage for most intervals is 15 percent or greater and, as the airborne data sample indicates, only 20 percent of foreign aircraft have TCAS.

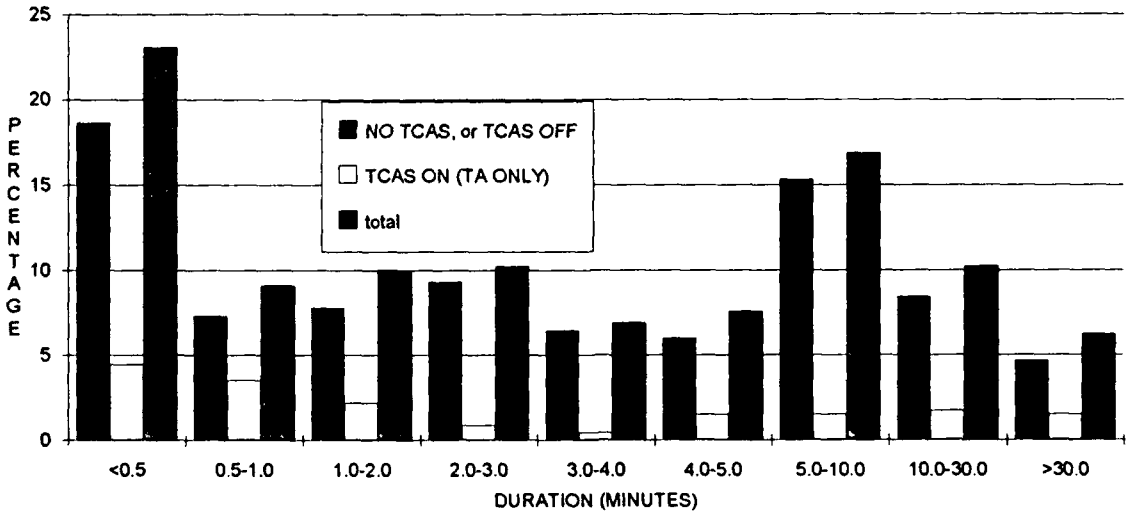

FIGURE 7. TCAS STATUS ON-GROUND FOREIGN AIRCRAFT

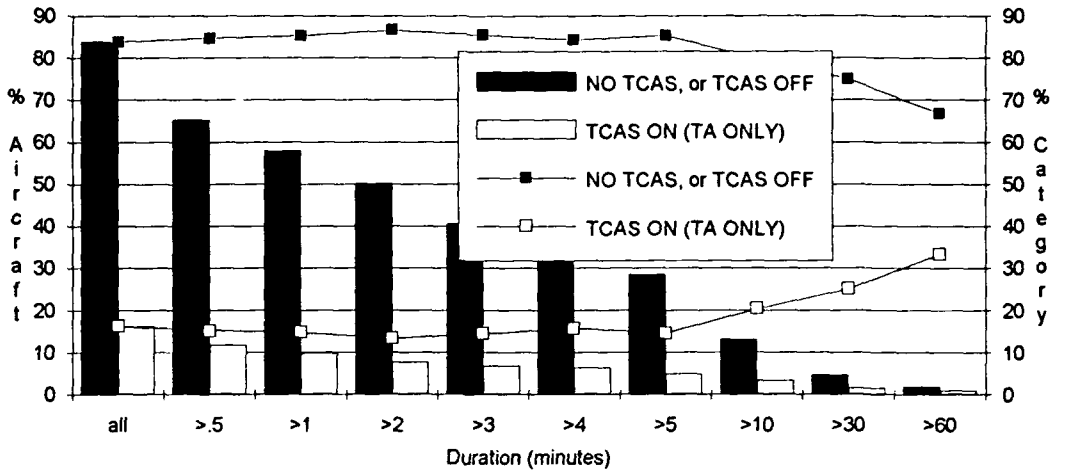

FIGURE 8. TCAS STATUS ON-GROUND FOREIGN AIRCRAFT PERCENTAGE CURVE

Figure 9 compares foreign and domestic on ground aircraft that have TCAS on. Again, the data are presented with respect to status duration. The bar chart shows the percentage of foreign vs. domestic aircraft with TCAS on. The line chart shows the percentage of on-ground foreign and domestic aircraft present. The percentage of foreign and domestic aircraft is uniform across the x-axis (line chart), but the percentage of foreign aircraft increases with longer time intervals (bar chart).

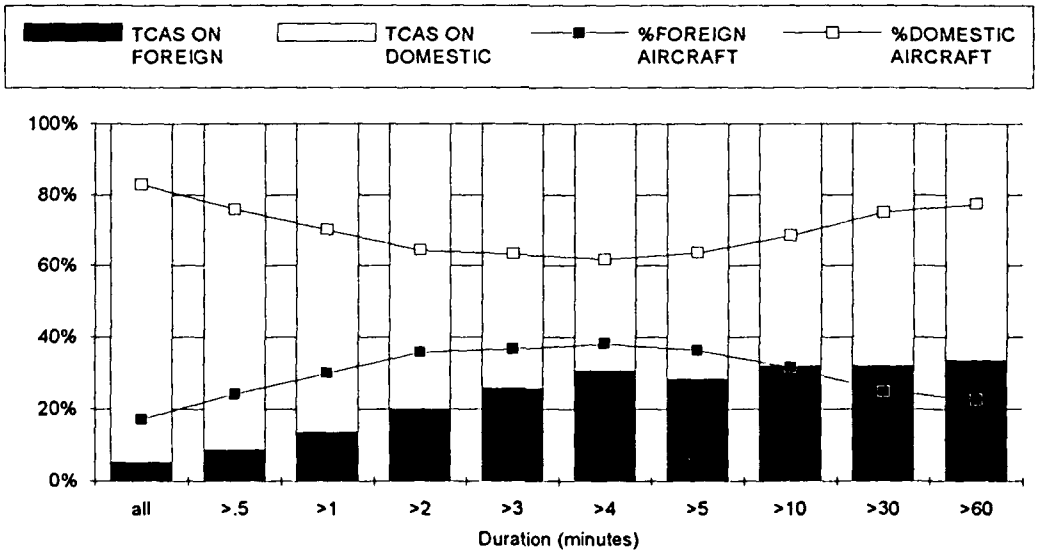

FIGURE 9. FOREIGN AND DOMESTIC ON-GROUND AIRCRAFT WITH TCAS ON

With future installations of DATAS for TCAS and environment monitoring, attempts will be made to best cover air and ground traffic. With a large sample of ground traffic data, a more accurate analysis of ground data will be possible along with the ability to show the percent of time there are two, three, or more operational on-ground TCAS units at a time.

AIRBORNE AIRCRAFT REPORTING "ON THE GROUND"

From the data collected in Los Angeles, it was discovered that six different aircraft had reported "ON THE GROUND" status when airborne. The airborne status of Mode S aircraft is reported in the Vertical Status (VS) field of the special surveillance replies (DF=0, 16), and the Flight Status (FS) field of the surveillance replies (DF=4, 5, 20, 21). DATAS acquires the VS field via a DF=0 reply and the FS field via a DF=5 reply during routine surveillance. TCAS uses the DF=0 Mode S reply when tracking aircraft. If the VS is reported incorrectly the aircraft may not be tracked by other TCAS units. All six aircraft consistently reported "ON THE GROUND" status in both the VS and FS fields and there were no records of any of them reporting "AIRBORNE." Table 1 identifies the six aircraft. Four of the aircraft were recorded on more than one flight, one was recorded on 14 separate flights.

TABLE 1. AIRBORNE AIRCRAFT REPORTING "ON THE GROUND"

Sample Size	= 2174 unique aircraft
Number of Erroneous Aircraft	= 6
Percentage of Erroneous Aircraft	= 0.275

Mode S Addr.	# Flights
A42BC7	1
A64CCF	1
A671F0	14
A8BBFF	6
A8EAEA	10
A971B4	2

The data acquired for the six aircraft was examined to determine if the VS might be inverted. The VS for all six is always a "1" for "ON THE GROUND." There is no conclusive evidence that any of the data were collected when they were really on the ground. Better ground coverage will help make this determination in the future. All six aircraft had fully operational TCAS units with vertical RA capability. The aircraft were recorded as high as 29,000 feet while reporting "ON THE GROUND." Table 2 shows the data recorded for aircraft A8BBFF as a sample. The flight data for Mode S aircraft A8BBFF were reduced and presented to show the time spans and altitude ranges for the six flights that were recorded. Aircraft A8BBFF reported "ON THE GROUND" in every reply for all six flights.

TABLE 2. MODE S AIRCRAFT A8BBFF FLIGHT DATA

Date	Start Time	End Time	ALT1	ALTn
12/25/92	21:23:13	21:31:03	10400	725
01/03/93	22:41:00	22:44:04	5675	875
01/05/93	21:52:54	21:59:57	7025	250
01/06/93	7:29:44	7:34:58	2025	12200
01/07/93	10:10:31	10:19:14	7075	600
01/14/93	0:10:40	0:18:11	9975	800

ON THE GROUND AIRCRAFT REPORTING "AIRBORNE"

After discovering airborne aircraft reporting "ON THE GROUND" VS, the data were tested for on the ground aircraft reporting "AIRBORNE." This search was not as cut and dry as the latter for several reasons. As previously mentioned, the ground coverage was not as good as the airborne coverage in Los Angeles. Also, this test requires determination that an aircraft reporting "AIRBORNE" was really on the ground. To do this, the data must be searched for aircraft with airborne status at altitudes reported by aircraft on the ground. With no altitude correction, there is variation with barometric pressure in the on the ground altitude from approximately -200 to +400 feet. The data were corrected for this variation off-line and searched for aircraft that appeared to "hover" at or near the on-ground altitude. Table 3 shows the results of this search. There are six different aircraft appearing in table 3. The altitudes reported by these aircraft are at or near the altitude reported by other aircraft with an "ON THE GROUND" VS. The conclusive factors in each of these records are the long duration and number of valid replies recorded. These aircraft cannot realistically be sustaining these altitudes for these lengths of time. The entire database was searched for records of any of these aircraft reporting "ON THE GROUND" at any other times, and there were none with one exception. Aircraft 750001 was recorded reporting "ON THE GROUND" on 15 other occasions, all of which were on separate days, and different days than indicated in table 3. It appears that this aircraft has an intermittent error in the VS field.

TABLE 3. ON THE GROUND TARGETS REPORTING "AIRBORNE"

							------ REPLIES ------		
Mode S	Date	Time Span		Duration	ALT1	ALTn	Valid	Corr	Bad
750001	12/15/92	1:25:01	1:30:06	0:05:05	75	75	19	8	39
750001	12/20/92	1:39:03	1:47:47	0:08:44	-125	-150	19	17	45
750001	12/29/92	1:14:24	1:16:09	0:01:45	100	100	4	3	34
750001	12/29/92	1:22:07	1:32:52	0:10:45	75	100	15	39	68
750001	1/14/93	1:12:49	1:21:38	0:08:49	150	125	13	36	35
750001	1/26/93	1:13:15	1:19:15	0:06:00	50	50	5	8	34
7C4828	12/22/92	22:49:50	22:58:06	0:08:16	125	-125	16	25	28
A6B7EE	1/2/93	22:43:00	22:44:28	0:01:28	50	50	7	2	7
A6B7EE	1/2/93	22:46:54	22:47:10	0:00:16	25	50	2	1	2
A8D00D	1/5/93	23:07:25	23:12:04	0:04:39	150	125	7	19	18
A8D00D	1/5/93	23:13:43	23:16:17	0:02:34	125	125	13	12	1
AB44B4	1/2/93	0:13:25	0:18:46	0:05:21	50	50	12	18	23
AD1852	12/30/92	10:18:41	10:19:27	0:00:46	-200	-200	6	1	2

ILLEGAL MODE S ID'S

During the data collection period of December 14, 1992, to January 15, 1993, there were a total of 117 flights during this period with illegal Mode S addresses. The individual case information is shown on table 4 (obvious repeats of the same illegal Mode S ID were not included). The identification of the airline has also been removed from this table. This table contains the information for aircraft which were identified by air traffic personnel. Air traffic personnel at the LAX Terminal Radar Approach Control Facility (TRACON) were given the ATCRBS code and time of day for the flights with illegal Mode S addresses and they returned the flight ID. They had some problems at LAX and were unable to provide us information on all the aircraft. We finally ended up giving the information to personnel at the LAX ARTCC in order to get the information.

The most common illegal address was all zeros. There were 27 flights with this address. Of the 16 flights which were identified, 11 flights were identified as a South American carrier, and 5 as a European. ***On January 5, two aircraft with the same Mode S ID of all zeros landed at LAX within 10 minutes of each other. This is a potentially dangerous situation as they both occupied the same airspace and either one or both may <u>not</u> be properly tracked by other TCAS (dependent on the manufacturer of the system).***

Figure 10 shows the dates and coverage times of the Mode S ID's which were all zeros. Only 26 of them are shown on this graph as the other was an en route flight. The aircraft which were identified by air traffic personnel came from only two carriers (the South American and European carriers mentioned above). These flights are identified in figure 10 by either S or T. If you assume that the others are also from those two carriers, they can probably be identified by the time of day. All "T" flights occurred between 21:00 and 01:00. All "S" flights occurred between 13:00 and 18:00. Using this information, seven of the unidentified flights are probably from "T" and three are from "S."

TABLE 4. ILLEGAL MODE S ADDRESSES AT LAX

Date	Time	Mode S ID	ATCRBS Code	Aircraft ID	Comments
12/15	09:40	8AAE94	7174	xxx565	Airline 4 (seen at JFK,PHL and DFW)
	11:10	89900B	0022	xxx006	Airline 2
	13:23	899044	0034	xxx012	Airline 1
	14:14	89900B	7242	xxx005	Airline 2
12/16	13:45	899043	3311	xxx012	Airline 1
12/18	21:35	000000	7212	????	
12/19	18:08	000000	1362	????	
	22:00	000000	7242	????	
12/21	21:00	000000	1013	????	
12/22	00:38	000000	1007	xxx711	Airline T
	20:40	000000	1055	xx2510	Airline T
12/23	13:50	000000	2105	xxx931	Airline S
12/26	15:32	000000	6654	xxx931	Airline S
	17:35	000000	7274	xxx932	Airline S
12/27	00:46	000000	3302	xxx611	Airline T
12:21	21:00	8912A3	0535	xxx579	Airline 4
	14:02	8912A3	7332	xxx579	Airline 4
	16:15	0008BD	3677	????	NO IFR FLIGHT PLAN
12/28	18:15	CC0D6A	2172	xxx001	Airline 3
	19:10	0008BD	1032	Nxxxxx	Private Aircraft
1/1	23:34	000000	3303	xxx611	Airline T
1/3	01:25	000000	3341	xxx611	Airline T
	22:40	000000	3345	????	NO DATA
	23:35	000000	7231	xxx2510	Airline T
1/4	22:35	000000	1056	xxx2510	Airline T
	23:50	000000	7231	xxx3510	Airline T
1/5	12:45	89900D	0006	xxx005	Airline 2
	22:20	000000	7244	xx2510	Airline T
	22:30	000000	7364	xx3510	Airline T
1/6	00:20	000000	1057	????	
1/7	12:45	CC0D6A	0065	xxx002	Airline 3
	18:00	000000	1773	????	NO DATA
1/8	18:00	CC0D6A	2121	xxx001	Airline 3
	22:29	000000	7217	xx2510	Airline T
1/9	00:20	000000	7221	????	
1/10	01:32	000000	3255	NO DATA	COMPUTER SHUTDOWN
	12:50	CC0D6A	0037	xxx002	Airline 3
	14:15	000000	7365	xxx931	Airline S
	17:50	000000	7360	xxx932	Airline S
1/11	11:35	89900D	0014	NO DATA	
	13:49	899043	3251	xxx012	Airline 1
	14:35	89900D	6773	NO DATA	
	18:13	CC0D6A	7316	NO DATA	
1/15	22:24	000000	7210	????	
1/16	00:47	000000	1006	????	

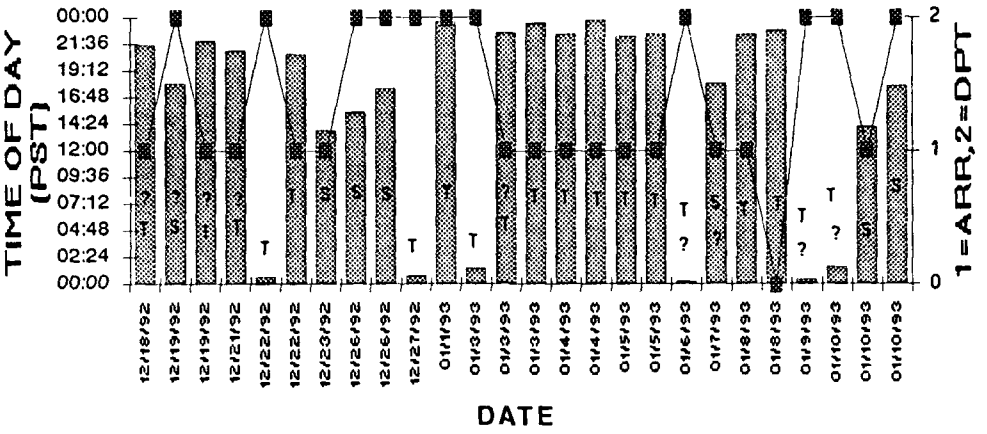

FIGURE 10. ARRIVAL TIME OF ZERO ID FLIGHTS

Figure 11 shows the number of flights as a function of the illegal Mode S address. There were a total of 43 illegally addressed flights by Airline 1 (21 by "899043" and 22 by "899044"). One of these aircraft was seen almost every day during the data collection. These two aircraft ***were*** equipped with TCAS. There were a total of 42 flights by Airline 2 (10 by "89900B," 15 by "89900C" and 17 by "89900D"). One of these three was also seen almost every day, but these aircraft always indicated "***no TCAS.***"

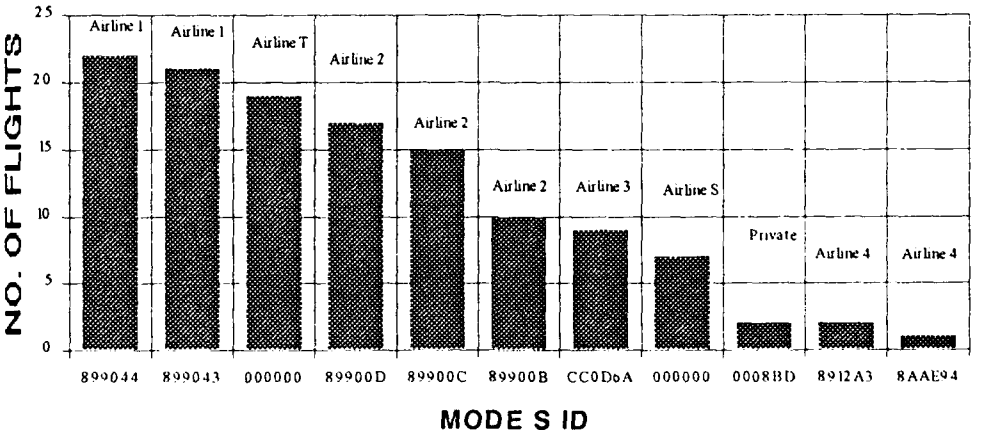

FIGURE 11. ILLEGAL MODE S ID FLIGHT DISTRIBUTION

There were nine flights by address "CC0D6A" from Airline 3. The correct addresses for the originating country start with "C8" and there were several flights by "C80D6A." The similarity of Mode S addresses raised a question. "Are these two Mode S addresses really from the same plane"? Figure 12

shows a very unique pattern: (1) note that the times of the two aircraft are all between 12:00 and 13:00 and approximately 18:00; (2) note that they are never both at LAX on the same day (C8D06A was there on 12/18, 12/27, 12/28, etc.). This is very convincing evidence that the Mode S address of this aircraft is sometimes different by a single bit.

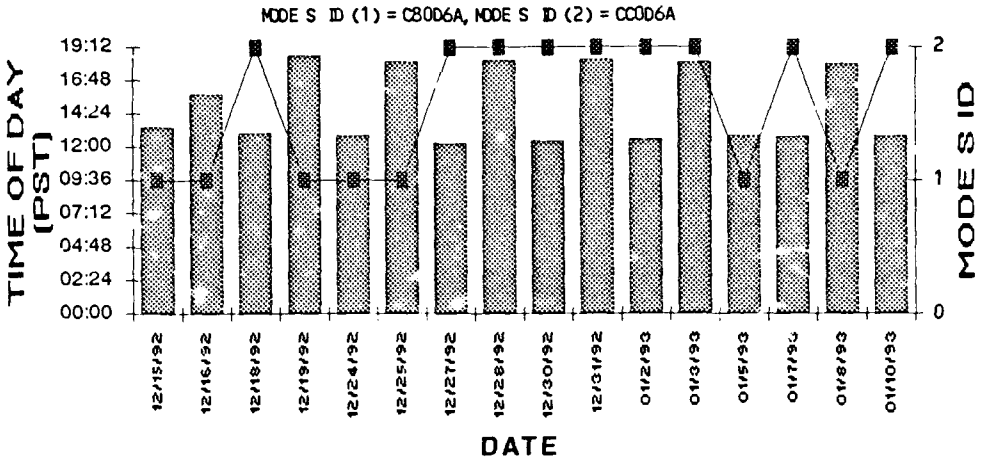

FIGURE 12. COMPARISON OF C80D6A AND CC0D6A

There were also three illegally addressed flights by Airline 4 (two by "8912A3," and one by "8AAE94" which had been seen earlier at JFK, Philadelphia (PHL) and DFW). All U.S. carriers Mode S ID's start with the letter "A" and all the illegal flights in this group contained "8" as the first "hexadecimal" character. This may result from one broken wire in the harness or perhaps the improper loading of the address into memory for use when the unit is powered up. The database was searched for occurrences of both addresses "AAAE94" and "A912A3," and neither was found. According to the program which relates Mode S ID to tail number, however, "AAAE94" is allocated to Airline 4 but "A912A3" is not. It could not be determined whether this address change results in the same address for the duration of the flight or it changes while in flight (potentially much more serious). The entire database was searched for address changes in-flight and none were found (see the discussion later). There were also two flights recorded of an illegally addressed private aircraft.

Mode S address errors, such as those discussed here, are easily detected by DATAS and, presumably, a Mode S sensor after their deployment, because the bits in error cause the assigned country code to become undefined. These are flagged by DATAS as illegal addresses. If such bit problems are occurring, they could easily affect bits that cause an address to be changed to another legal Mode S address assigned to the same, or even a different country. Such incorrectly addressed aircraft could, potentially, no longer have a discrete

address and could go virtually undetected. This problem could severely affect end systems that rely on true discrete addresses such as Data Link and TCAS.

RESOLUTION ADVISORIES

There were a total of 182 RA's containing 374 segments during the data collection period. The RA's which appeared standard were not investigated thoroughly for similarities as there was no compelling reason to do so. Investigation of the "all zero RA" data which are collected by DATAS, however, is continuing. This phenomena was first noticed at JFK when DATAS was collecting data there. Analysis of LAX RA data show that there are occurrences of the "all zero" RA's which do not timeout (RA reporting by the transponder should terminate 18 seconds after the end of the alert) as seen on the east coast (this was not seen at Dallas). There were a total of 55 RA's (with all zero content) which lasted for longer than 1 minute. These were reported by 30 different aircraft. Figure 13 below shows a summary of these data. The most frequent offender was "A2665F" which had a total of six RA's with all zeroes lasting from approximately 1.5 minutes to slightly over 10 minutes each. This aircraft alone reported RA's with all zeroes for a total of approximately 30 minutes during the data collection period. This list appears to be the same class of aircraft (commuters) as that seen on the east coast. Once an RA occurs, it apparently does not timeout as, in all cases, the RA was reported with all zero data throughout the entire coverage period. "A2665F" on one occasion, reported an all zero RA for the entire coverage time at two intervals about 4 hours apart.

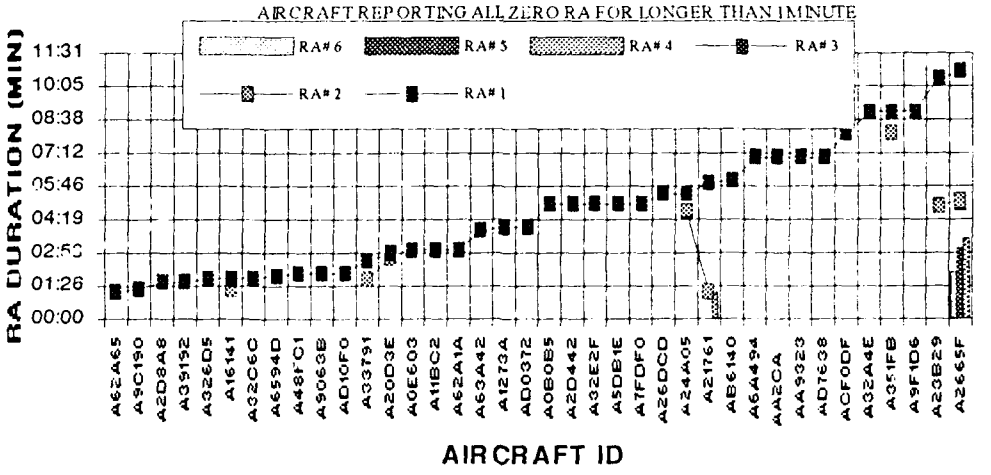

FIGURE 13. LAX ZERO RA'S LONGER THAN 1 MINUTE

The tail numbers were then ascertained via a program which relates Mode S ID to aircraft tail number. The aircraft registration microfiche was then searched to identify the airlines associated with these tail numbers. Some of the airlines were verified by air traffic personnel at LAX. In many cases, the owner

is listed as a bank or leasing company. Air traffic personnel do not use the tail number for their work. Rather, the air traffic control (ATC) system relies only on the flight number which is associated with an aircraft when a flight plan is filed. The particular aircraft that is flying is not important, nor associated in the ATC system. The tail number, when identified by the program which relates it to the Mode S address, can give an idea as to which airline might have originally applied for the Mode S address. There are one or more letters in the tail number from which the more common airline names can be ascertained (i.e., xxxUS is usually USAIR, xxxUA is usually United Airlines). However, it was found that these were not always correct. The airplane may currently be operated by a different airline. The original tail number stays with the aircraft no matter which airline currently operates or uses it. As a result, we have found no available means of determining the airline to contact by correlating the Mode S address and aircraft tail number. All the existing databases provide current registered owners of aircraft (usually banks) associated with the aircraft tail number.

The all zero RA problem is not significant at the present time as the existing ATCRBS system and the TCAS are unaware of the problem. After the Mode S systems are installed, however, they may solicit RA information from the aircraft. The result will be a significant burden on the already limited available time for Data Link activity, etc. If RA data are presented to the air traffic controllers, the data will be a nuisance as these messages will last for the duration of the flights.

MODE S REPORTED ALTITUDE INCREMENTS

In present ATCRBS systems, the altitude is reported in 100-foot increments in the Mode C replies. Mode S altitude can be reported in either 25- or 100-foot increments. A single bit in the Mode S reply is used to designate the altitude type used since the reporting schemes are quite different. The 100-foot altitude increment replies use the same "Gray Code" scheme used in the present ATCRBS system. The 25-foot altitude is simply encoded in binary with 25-foot resolution. The TCAS program office had expressed an interest in how many Mode S aircraft report altitude using each scheme. It is interesting to note that 96 percent of the aircraft which are equipped with Mode S report the altitude with 25-foot resolution.

DOWNLINK DATA

The downlink data were collected at LAX over the 3-day period January 26 to 28, 1993. The DATAS was setup at the ASR-9 radar site for connection to the ATCBI-4 receiver output. In this manner, the counts of ATCRBS and Mode S replies directly reflects the amount seen by the ground ATCRBS processing system.

The data recorded included ATCRBS and Mode S decode counts and the Mode S reply data. In order to save disk storage space, the time of arrivals (of each reply) were only identified to a specific 5 millisecond interval. The data were broken into files of 5-minute duration in order to keep the file sizes down for ease of analysis when using external database programs. Even with this measure, the data stored were approximately 800 kilobytes/5-minute interval. The total data stored during the data collection period was 316 megabytes.

Figure 14 shows the ATCRBS reply counts as a function of time of day over the 3-day period. As expected, the ATCRBS reply rate is a function of traffic and the rates during the late night and early morning hours are essentially zero. During the data collection period, the counts were much lower than expected. During the peak periods, the average ATCRBS fruit rate was only about 1 kilobyte/second. Nothing was wrong with the system and the fruit count from the ASR-9 during the peak period was approximately 3 kilobytes/scan which correlates roughly with the data. The analog video, however, looked significantly different than that normally observed as the raw video on an ATCRBS system. Local personnel stated that it was not significantly different from normal.

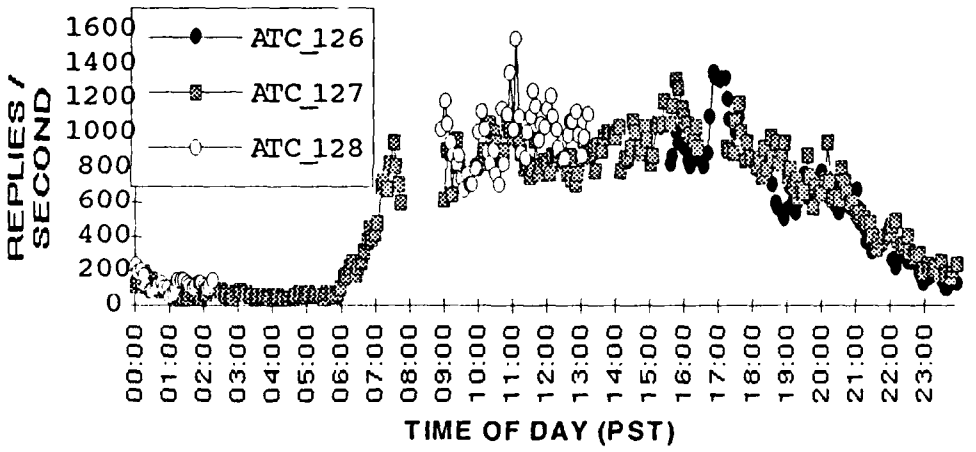

FIGURE 14. DOWNLINK ATCRBS REPLIES

Figure 15 shows the Mode S replies as a function of time of day. These values are nearly an order of magnitude lower than those measured in Chicago. At this time, there is no explanation for this. The average rates during the peak period of the day are normally only 15 to 20 replies per second. The highest rate was 44 replies per second, certainly a rate which can cause no problem for the existing ATCRBS system.

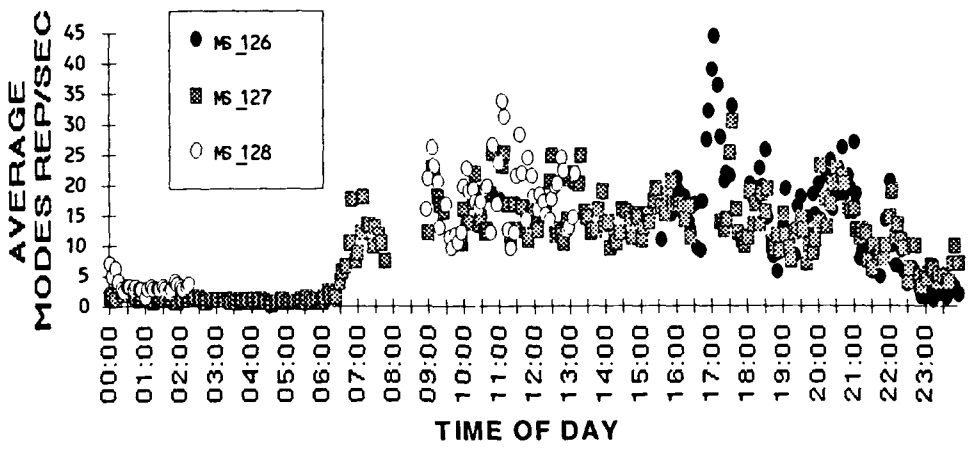

FIGURE 15. DOWNLINK MODE S REPLY COUNTS

An extensive analysis of the downlink Mode S data were made to see what useful data could be gathered. The quality of the data were degraded by the fact that DATAS was located approximately 100 feet from the ATCBI-4. The system does not have "line compensation" built in as short cables are normally used. The ATCBI receivers are also "linear" receivers with much less dynamic range than the normal "log" receiver of DATAS. An attempt was made to adjust the various thresholds in DATAS to optimize them for this input. The DATAS Mode S reply processor uses "confidence" data in its code correction scheme. This "confidence" is based on the amplitude of the input signals. The Mode S downlink modulation scheme is pulse position modulation. This means that each bit interval is divided into two halves. If a pulse is present in the first half of the interval, the bit is a "1," and if a pulse is present in the second half, the bit is a "0." Thus, with a degraded input, the quality of the "confidence" data was also degraded. Thus, an analysis of the Mode S data is based only on those replies which showed a "high confidence" on at least 48 of the 56 bits of the message.

The data were filtered using the high confidence criteria and then sorted according to Downlink Format (DF) code. The TCAS system uses primarily DF0 and DF16. All Mode S transponders "squitter (unsolicited reply)" DF11 approximately once per second. The TCAS system uses this DF11 to determine the presence of a new Mode S equipped aircraft and initiates the acquisition phase of its tracking. The DF16 messages are used only for coordination between aircraft. Figure 16 shows the distribution of DF codes measured on the downlink as a function of "time of day." These data are the average percentage of each DF code type. There are some discontinuities as we had several outages (ATCBI channel changes, DATAS "disk full," and a change of the ATCBI antenna motor) causing unavailability of data around the clock each day. As indicated, the percentage of replies which did not meet the confidence bit criteria (minimum 48 of 56 high confidence) remains fairly constant at about

40 to 50 percent regardless of the time of day. This indicates that it is probably not a function of the ATCRBS and Mode S fruit rates which varied widely during the course of the day. The number of DF0's was usually about 5 times greater than the number of DF11's when there was any significant activity (the number DF16's were insignificant). As indicated in figure 16, at times when the Mode S fruit was very low, there were more DF11's than DF0's. These DF0's are used for surveillance between TCAS aircraft while each aircraft always squitters once per second. The TCAS units interrogate only as often as required in order to keep the aircraft under surveillance.

Data from the 30 minutes surrounding the peak interval (44 replies/second at approximately 17:00 on 1/26/93) was the main source for analysis. This analysis showed replies from a total of 64 different Mode S equipped aircraft during this period. During this period, 40 aircraft were landing (see figure 17), 22 were taking off (see figure 18) and 2 were presumed en route to other airports or reported a constant altitude for their entire coverage period. The most active air carrier during the peak 1/2 hour was United Airlines, which had 7 arrivals and 6 departures.

Figure 19 shows the distribution of reply types during the peak period. As indicated, approximately 71 percent of the replies were DF0's from aircraft in the air. Approximately 13 percent were DF0's from aircraft on the ground and 14 percent were squitter replies which contained the address of the replying aircraft. This would indicate that approximately 15 percent of the replies during this period were from aircraft which were on the ground.

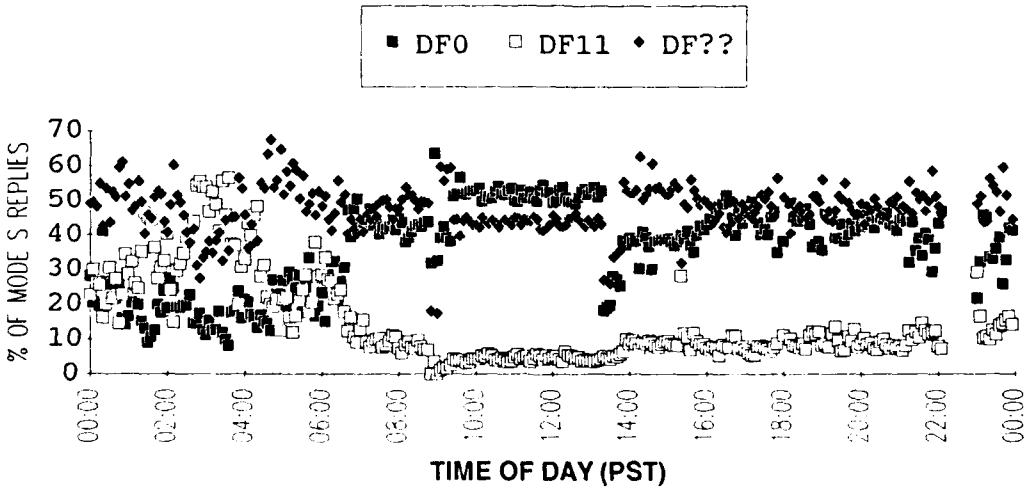

FIGURE 16. OVERALL DOWNLINK FORMAT CODE DISTRIBUTION

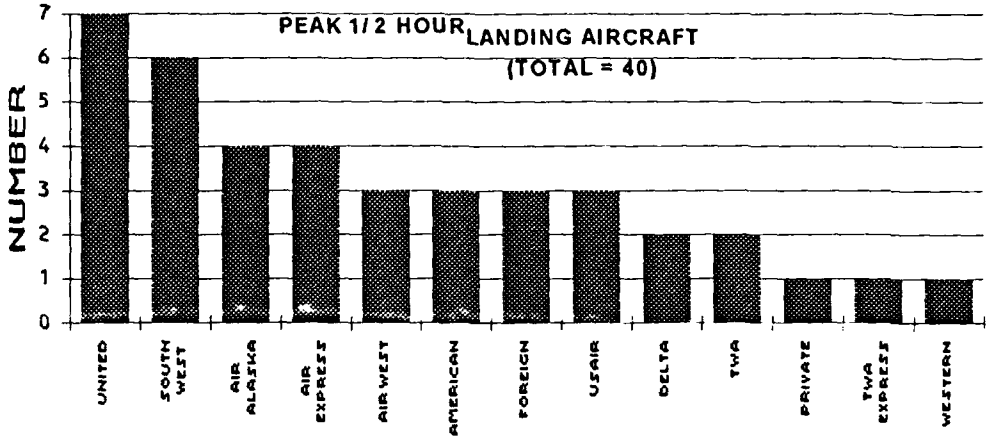

FIGURE 17. AIRCRAFT LANDING DURING THE PEAK PERIOD

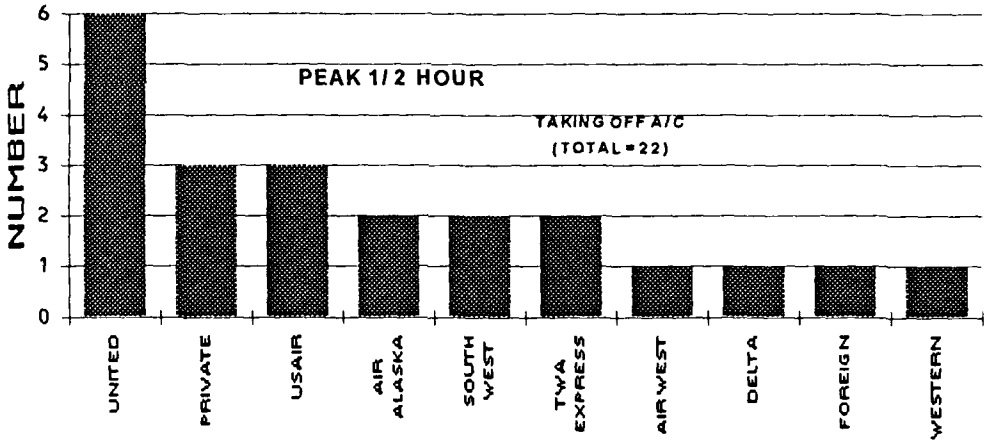

FIGURE 18. AIRCRAFT TAKING OFF DURING THE PEAK PERIOD

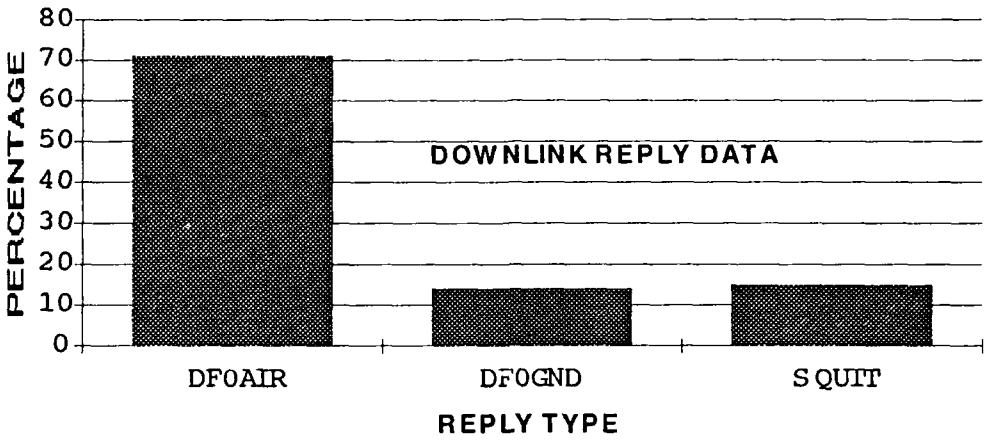

FIGURE 19. DF CODE DISTRIBUTION DURING THE PEAK PERIOD

Samples of reply data from a few individual aircraft are shown on figures 20 to 22. These are typical cases, which show the type of information which can be acquired. Figure 20 shows the data from one of the landing aircraft. The coverage period was approximately 10 minutes. The aircraft was initially picked up at an altitude of approximately 6,000 feet. The TCAS was operational with "RA" capability (RI field = 3). The altitude and RI field are plotted for the duration of coverage. The data show that the aircraft landed at approximately reply #118. The TCAS changed to the "TA" (RI=2) at approximately reply #112. Eleven percent of the replies were "Acquisition" replies (RI=12). These "Acquisition" replies are an indication of other aircraft in the process of initiating a track of that aircraft. Note also, the number of acquisition replies after the aircraft has landed.

Figure 21 shows an aircraft which is reporting altitude in 100-foot increments with a reported altitude which is constant at approximately 4,000 feet for the entire 20-minute period, an inordinately long interval in a terminal area. The possibility of a "stuck bit" (a fairly common occurrence in this type of altitude reporting) was investigated. This is not the case, however, as the only bit which could be stuck would make the altitude constant at approximately 1,400 to 1,500 feet. The aircraft was probably en route to a different facility as the "holding" altitude for landing at LAX is normally higher than 4,000 feet. The aircraft reported TCAS-OFF for the entire period. It was apparently being acquired by a significant number of other aircraft, however, as the number of acquisition replies (RI=12) was approximately 15 percent of the total.

Figure 22 shows the reply data of an aircraft which reported being airborne although it was on the ground during the entire period. As indicated, the number of replies is very low (only 20 during the 30-minute period), but every reply reported the VS incorrectly. This aircraft was also seen during the TCAS

Monitor portion of the data collection on January 5 (see table 3) when it also reported being airborne the entire flight (whether in the air or on the ground).

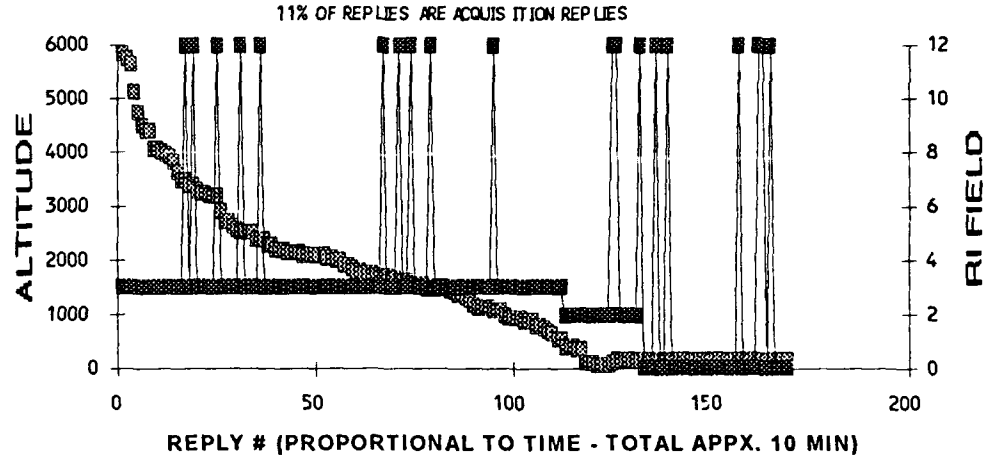

FIGURE 20. REPLY DATA OF "A07B32" DURING THE PEAK PERIOD

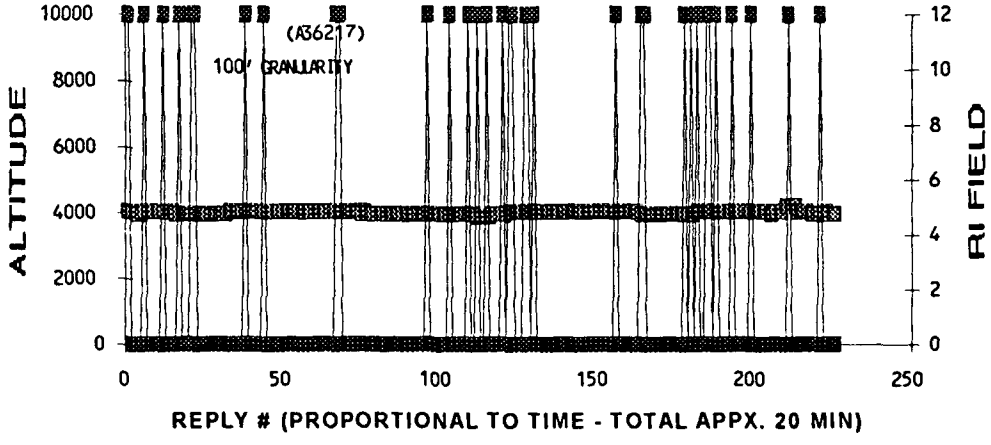

FIGURE 21. REPLY DATA OF "A36217" DURING THE PEAK PERIOD

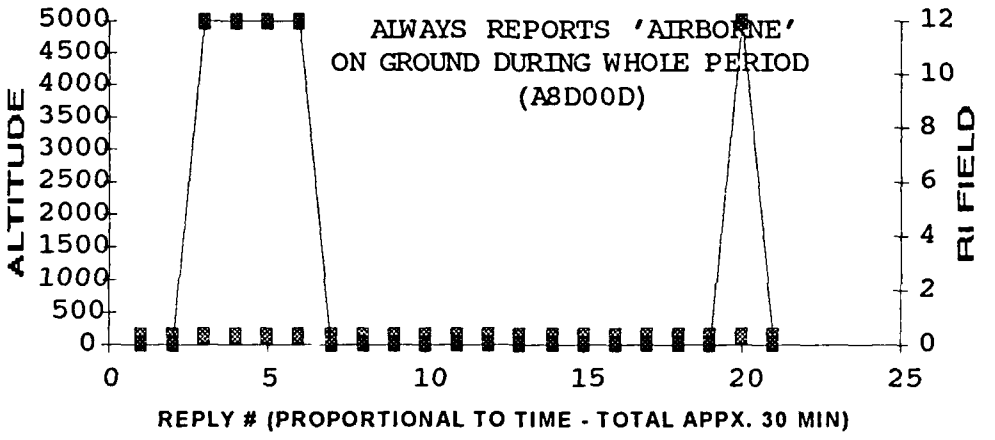

FIGURE 22. REPLY DATA OF "A8D00D" DURING THE PEAK PERIOD

The reply data from all 64 aircraft seen during the peak period was compiled and analyzed to determine the reported TCAS status. Figure 23 shows the results of that analysis. The data are divided into four groups: (1) All Aircraft, (2) Landing Aircraft, (3) Aircraft Taking Off, and (4) Aircraft which always reported TCAS OFF.

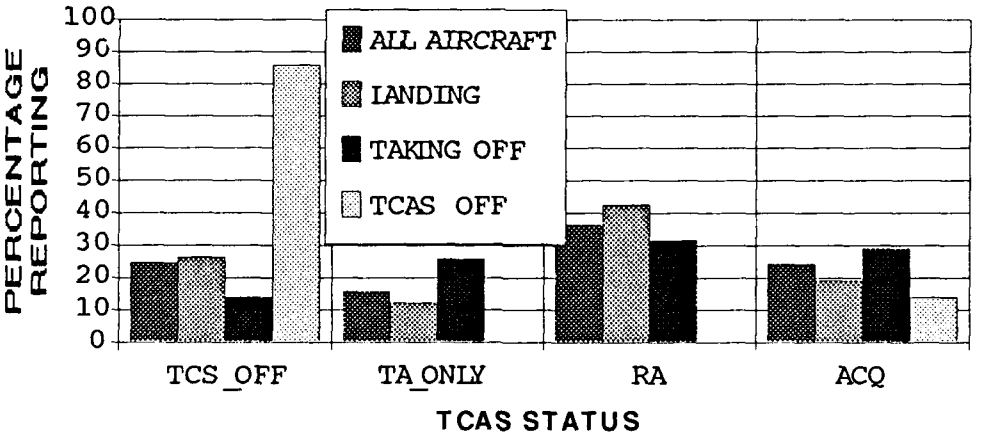

FIGURE 23. TCAS STATUS OF AIRCRAFT DURING THE PEAK PERIOD

When looking at "All Aircraft," it is seen that they report TCAS OFF approximately 23 percent of the time. They report TA Only approximately 16 percent and RA Mode approximately 36 percent of the time (the system is forced to TA mode below an altitude of 500 feet). This sample includes all aircraft, at all altitudes, whether airborne or on the ground. This appears to be compatible with the results of the TCAS monitor data of figures 12 and 13. Approximately 23 percent of all replies were "acquisition" replies. This is a

surprisingly high number, and indicates a lot of activity during the acquisition phase. One possible explanation, is poorer reliability of the air/ground link referenced to the air/air link normally used. Interrogations addressed to aircraft on the ground may, therefore, result in reinterrogation in order to get a satisfactory reply. It should be noted that this downlink sample is based on a single 1/2 hour during the interval which contained the peak Mode S reply rate.

"Landing Aircraft" reported TCAS OFF approximately 27 percent, TA ONLY - 11 percent, RA Mode - 42 percent and had 19 percent acquisition replies. "Departing Aircraft" reported TCAS OFF - 13 percent, TA ONLY - 26 percent, RA Mode - 31 percent and had 29 percent acquisition replies. "Aircraft with no TCAS" replied with acquisition replies 13 percent of the time.

DATA DISCUSSION

When data were collected at Chicago O'Hare, it was determined that approximately one-third of the interrogations were addressed to aircraft which were on the ground. Data collected at LAX (although the sample is much smaller) indicate that approximately 15 percent of replying aircraft were on the ground. The percentage of "Acquisition" replies (approximately 23 percent at LAX) indicates that aircraft are having difficulty in the acquisition of new aircraft and are being required to reinterrogate to achieve satisfactory replies.

It is well known, that there are severe reflection problems at Chicago O'Hare. These problems have required the employment of special measures in order to satisfactorily eliminate them. These problems will probably result in an even higher acquisition reinterrogation rate than that at LAX. This, when coupled with a high acquisition reply rate is a possible explanation for the difference in Mode S reply rates measured in Chicago and at LAX.

The downlink data collected during this effort was via an interface to the LAX ATCBI-4. While this enables us to accurately determine which replies affect the existing system, the mechanism is only sampling the total environment because of the scanning narrowbeam antenna pattern. While this method is adequate to measure effects to the ATCRBS processing system, it is now the consensus that data should be collected with an omnidirectional antenna pattern in order to measure the total environment. The logarithmic receiver of DATAS should also be used instead of the linear receiver of the ATCBI-4/5. Periodic interrogations should also be made by DATAS in order to determine the position of all aircraft which contribute to the sample as well as retrieve the ATCRBS data necessary to relate the aircraft to the ATC database. In this manner, it should be possible to characterize the "downlink" environment at the particular site.

It is recommended that the DATAS be returned to Chicago so that additional data can be collected in order to properly analyze the situation.

CONCLUSIONS

1. The domestic airline Mode S aircraft reported nearly 90 percent Traffic Alert and Collision Avoidance System (TCAS) equipage. Foreign equipage was only about 20 percent.

2. For the aircraft sample which had coverage on the ground, 48 percent of all aircraft had their transponders and TCAS on for less than 0.5 minutes after landing. Approximately 36 percent had the TCAS in the Traffic Advisory (TA) mode and the remaining 12 percent either had no TCAS or had it turned off. Approximately 17 percent of all aircraft had the transponder/TCAS on for .5 to 1 minute after landing. Some aircraft, however, had their transponders and TCAS on for longer than 1 hour while sitting on the ground.

3. Six aircraft out of a sample of 2,147 reported being on the ground when they were actually airborne. All six aircraft had fully operational TCAS units with vertical resolution advisory capability. The aircraft were recorded as high as 29,000 feet while reporting "ON THE GROUND."

4. As a result of the analysis of the "vertical status" reporting, it was determined that six aircraft reported being in the air when they were actually on the ground. One of these aircraft reported the "vertical status" properly on some flights, but the remainder always reported the status incorrectly.

5. Illegal Mode S ID's appear to fall into three categories:

   a. All zeros or all ones
   b. Apparent wiring errors or misinterpretations of specifications
   c. Single bit errors - possibly from startup

6. There is very convincing evidence that the Mode S address of the same aircraft is sometimes different by a single bit.

7. The transponder reporting of Resolution Advisories (RA's) with all zero data which do not terminate properly occurred frequently in Los Angeles. These are merely a nuisance now, but will become a problem after the implementation of Mode S.

8. Mode S equipped aircraft reported altitude in 25 feet increments in 96 percent of the cases.

9. There is no satisfactory way to identify the airline when knowing Mode S address. The airline registry which includes aircraft tail numbers show the owners of the aircraft which is usually a bank or leasing company, not the airline which operates it. Programs to cross reference Mode S ID's to tail numbers exist, but in many cases the tail number does not give an indication of the airline.

10. The highest Mode S reply rate measured in Los Angeles was 44 replies per second, certainly a rate which can cause no problem for the existing Air Traffic Control Radar Beacon System (ATCRBS) system.

11. Approximately 71 percent of the Mode S replies measured while monitoring the downlink environment were Downlink Formats (DF0's) from aircraft in the air. Approximately 13 percent were DF0's from aircraft on the ground. Since 84 percent of the total replies were DF0's, this would indicate that approximately 15 percent (13/84) of the replies during this period, were from aircraft which were on the ground. Approximately 14 percent of the replies were squitters (unsolicited Mode S All Call) which contained the address of the replying aircraft

12. When looking at all Mode S replies, it is seen that they report TCAS OFF approximately 23 percent of the time. They report "TA Only" approximately 16 percent and "Resolution Advisory (RA) Mode" approximately 36 percent of the time (the system is forced to TA mode below an altitude of 500 feet).

13. Approximately 23 percent of all Mode S replies were "acquisition" replies. This is a surprisingly high number, since it indicates a lot of activity during the acquisition phase. One possible explanation, is poorer reliability of the air/ground link which would result in reinterrogation in order to get a satisfactory reply.

RECOMMENDATIONS

It is now the consensus that data should be collected with an omnidirectional antenna pattern in order to determine the total environment. The logarithmic receiver of Data Link Test and Analysis System (DATAS) should also be used instead of the linear receiver of the Air Traffic Control Beacon Interrogator (ATCBI)-4/5. Periodic interrogations should also be made by DATAS in order to determine the position of all aircraft which contribute to the sample. In this manner, it should be possible to characterize the "downlink" environment at the particular site.

It is recommended that the DATAS be returned to Chicago, as well as other major airports, so that additional data can be collected in order to properly characterize both the uplink and downlink environment.

☆U.S. GOVERNMENT PRINTING OFFICE: 1993 - 704-078/80079